Manipulating the Coffee Ring Effect

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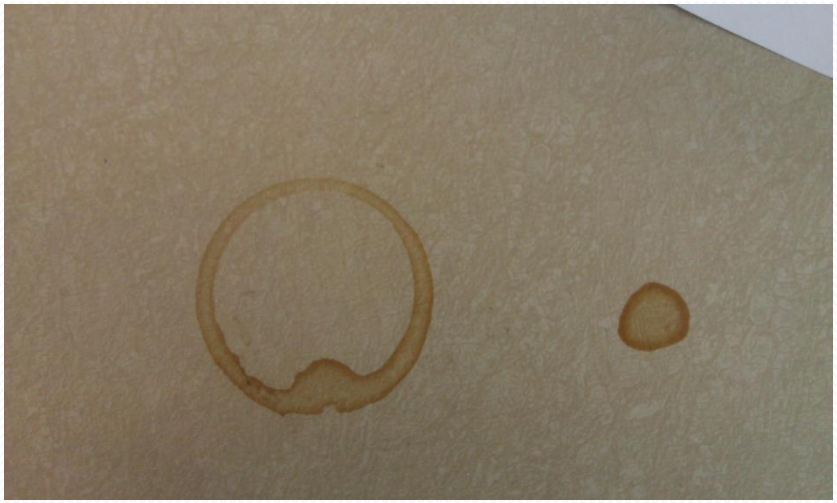
Coffee Ring Effect



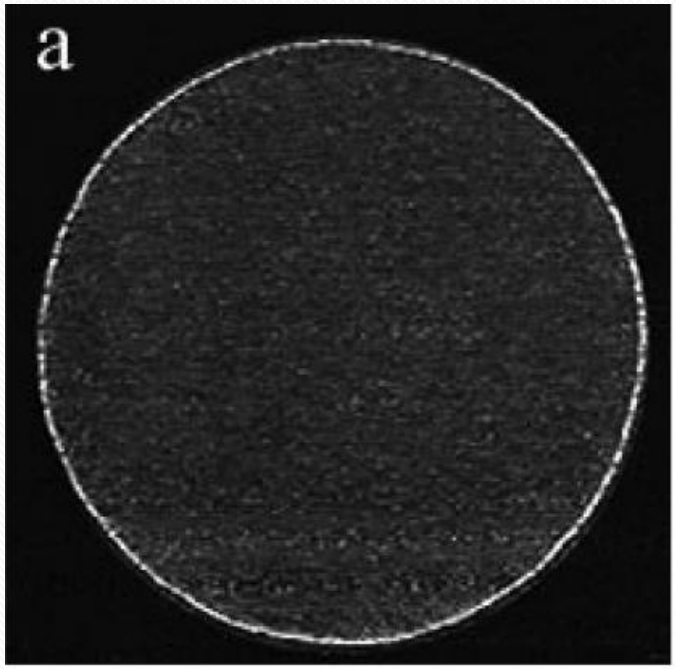
- What is the coffee ring effect?
- Why do we care?

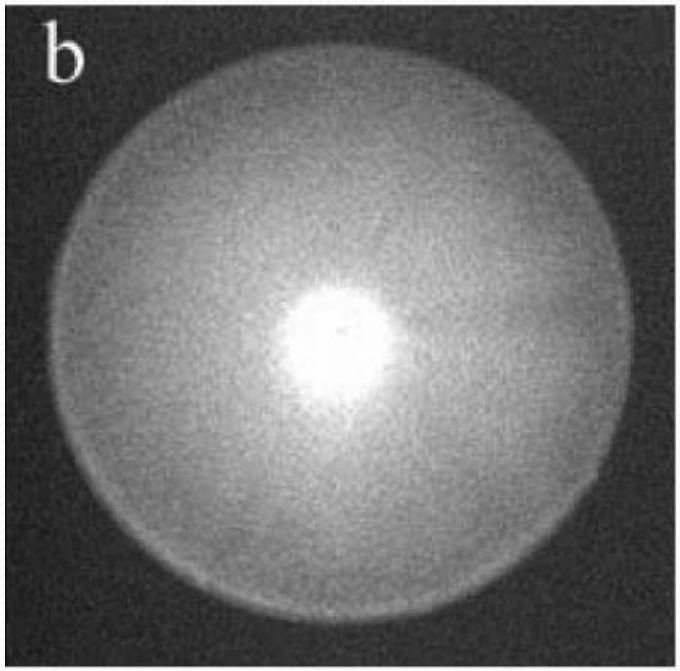
Formation of Coffee Rings

- Why do they form?
- What is required?
  - Contact angle
  - Pinning
  - Evaporation

Deegan, R.D., et al., "Capillary flow as the cause of ring stains from dried liquid drops", *Nature* **389**, 6653 (1997).

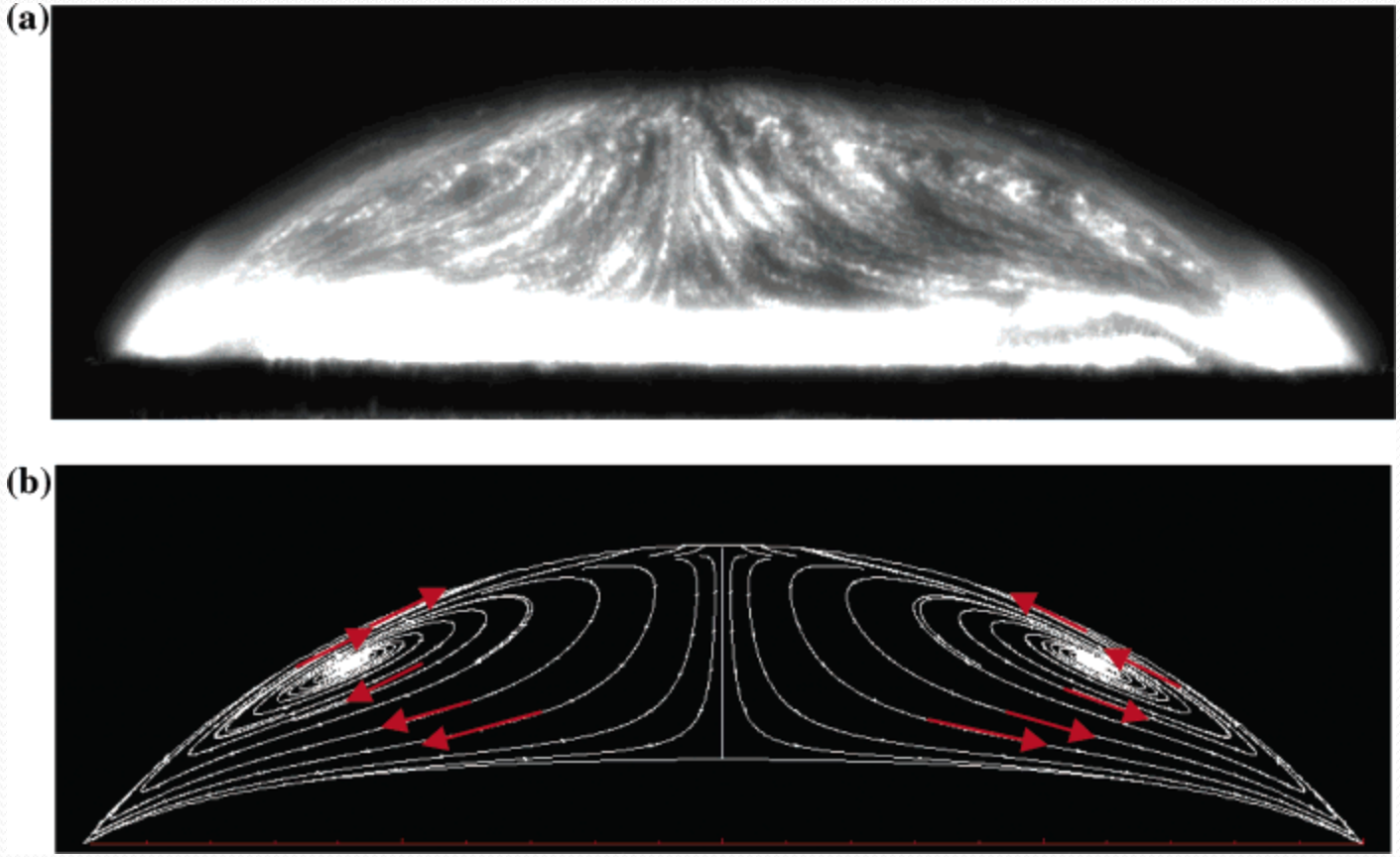
Reversing the Effect



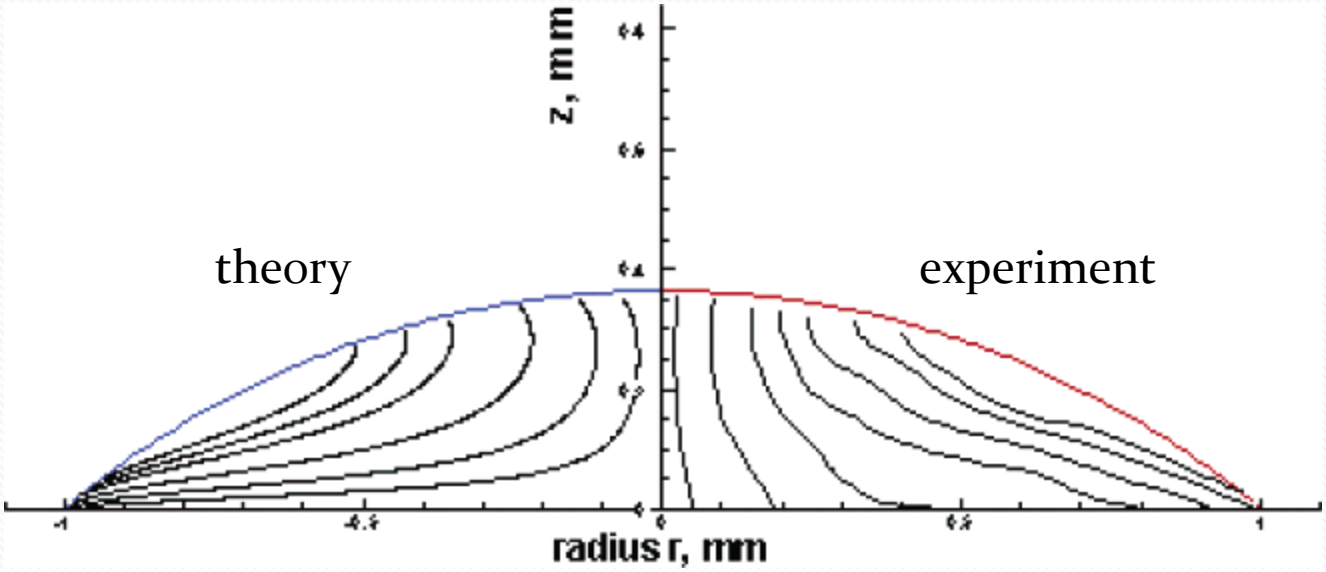


Hu, H. and R.G. Larson, "Marangoni Effect Reverses Coffee-Ring Depositions", *J. Phys. Chem. B* **110**, 14 (2006).

Marangoni Effect

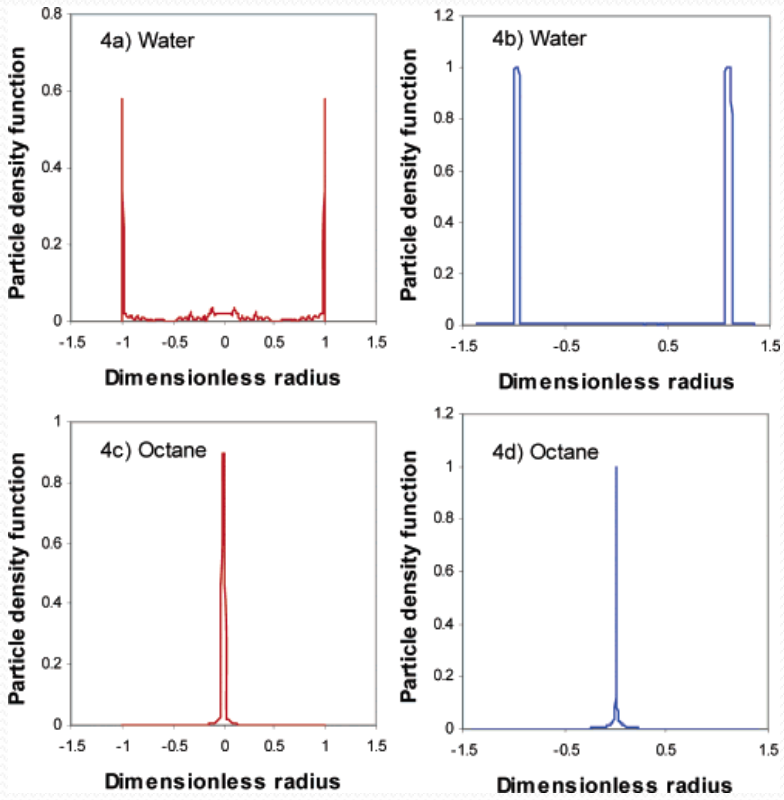


What's so different about water?



- Surfactant contaminants affecting surface tension?

Effect of Solvent on Ring Formation



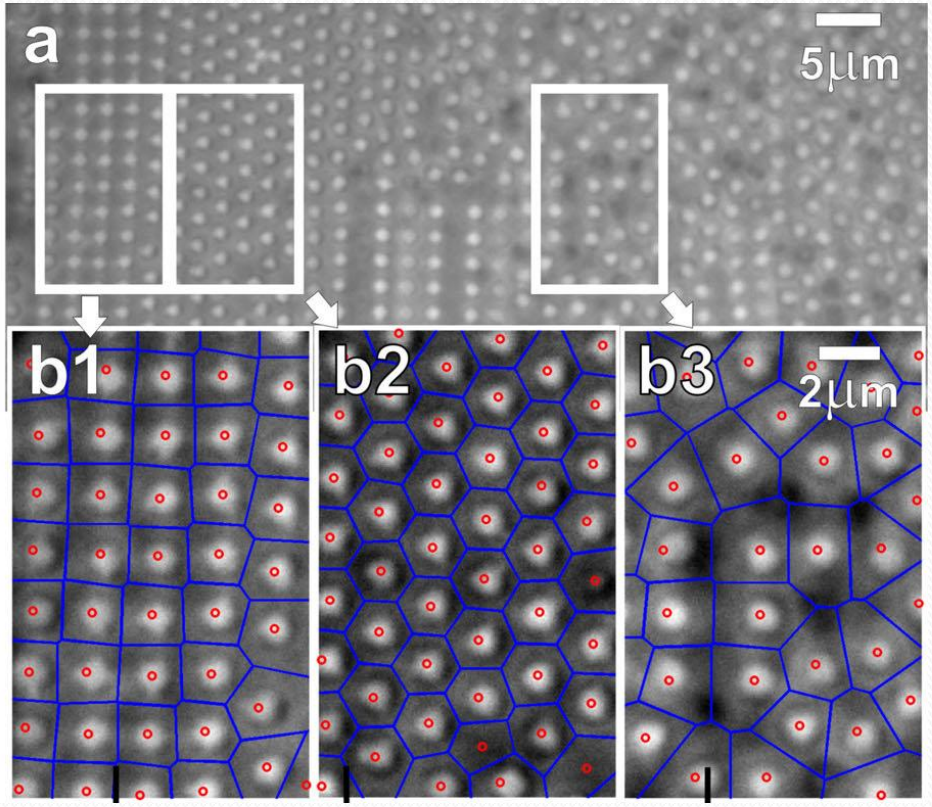
- Red = Experimental results
- Blue = Theoretical predictions
  - *(using experimentally determined Marangoni numbers)*

Back to Coffee Ring Formation…

- What is required?
  - Contact angle
  - Pinning
  - Evaporation
  - Suppression of Marangoni Effect
- How do particles arrange within the ring itself?

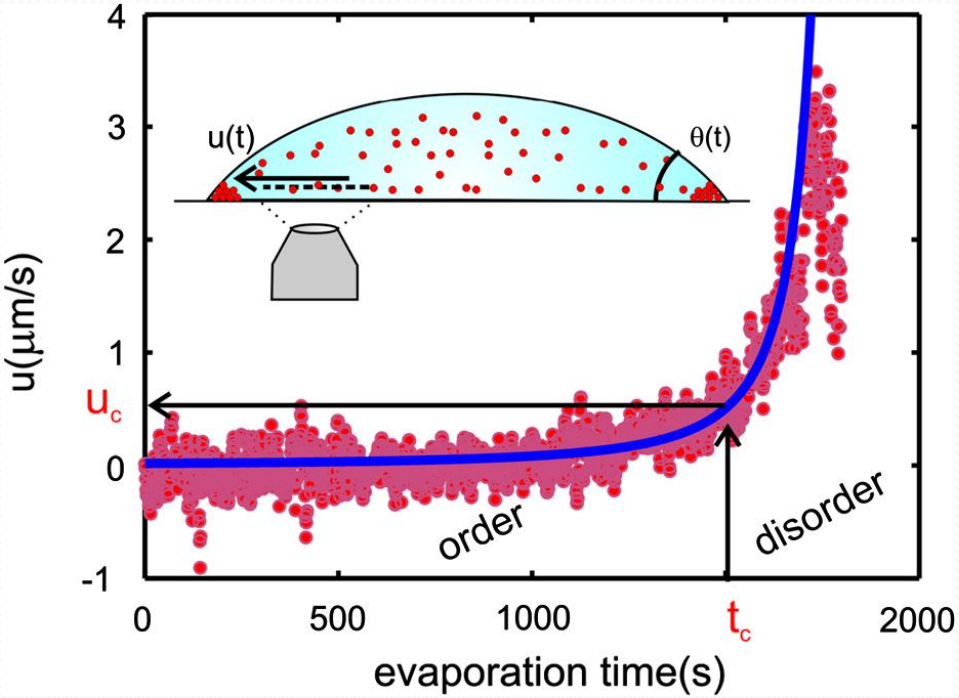
Order-to-Disorder Transition

- Particle arrangement is highly inhomogeneous!
  - Square packing
  - Hexagonal packing
  - Disordered
- Why the transition?



Marín, A.G., et al., "Order-to-Disorder Transition in Ring-Shaped Colloidal Stains", *PRL* **107**, 085502 (2011).

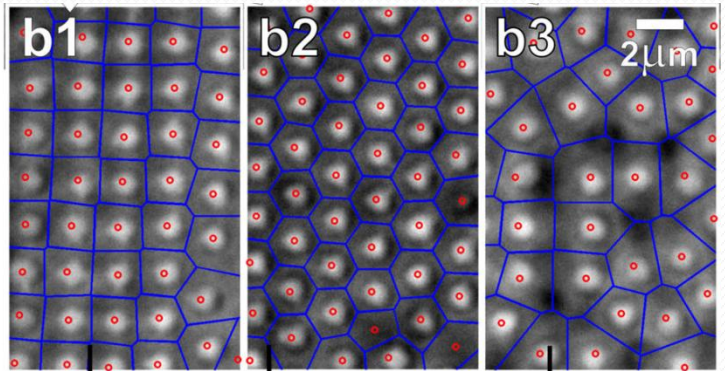
The “rush-hour”/Tetris analogy



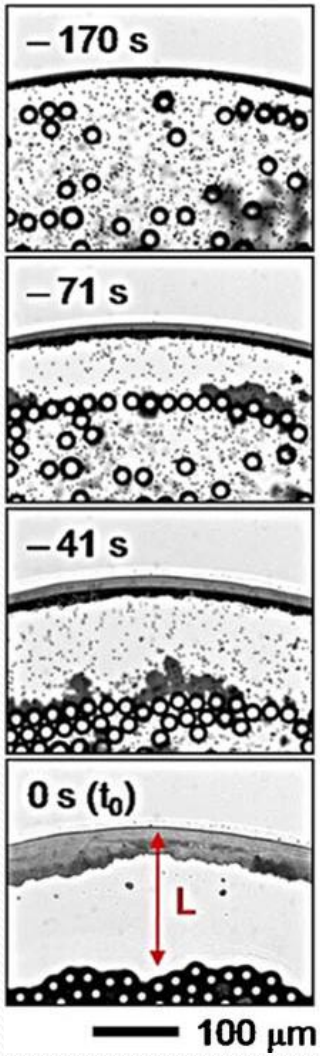
- Constant rate of evaporation
- Decrease in drop height means increase in radial velocity
- Time scale for Brownian motion

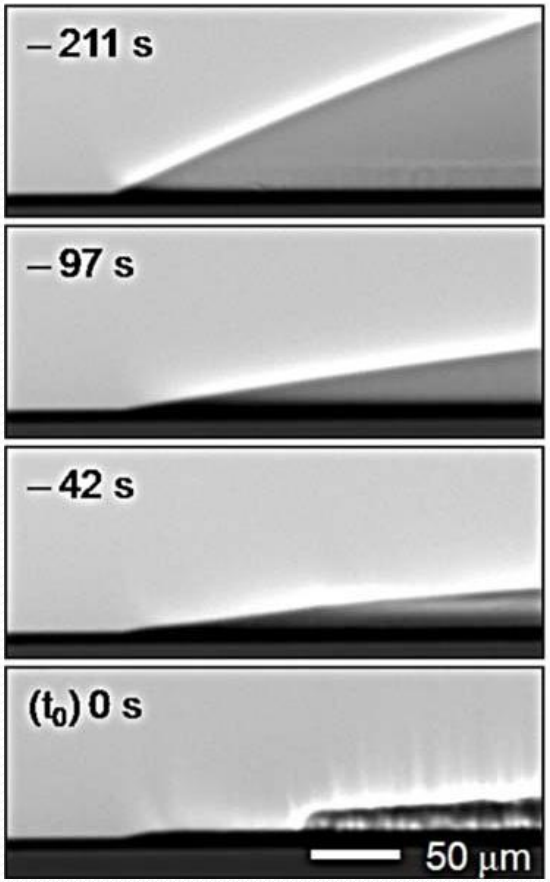
This isn't quite the whole story…

- Voronoi Areas
  - Blue boxes around particles
- Confinement
  - What happens near the droplet edges?



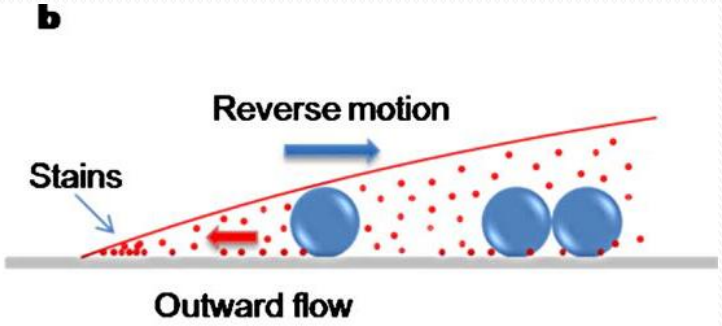
So how can we manipulate coffee rings?





Weon, B.M., and J.H. Je, "Capillary force repels coffee ring effect", *Phys Rev E* **82**, 015305 (2010).

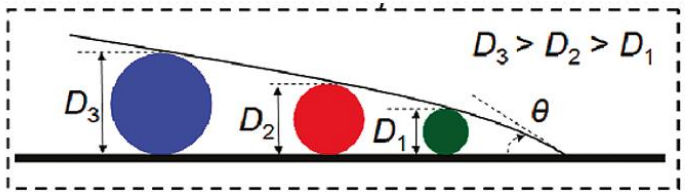
Geometric Constraints

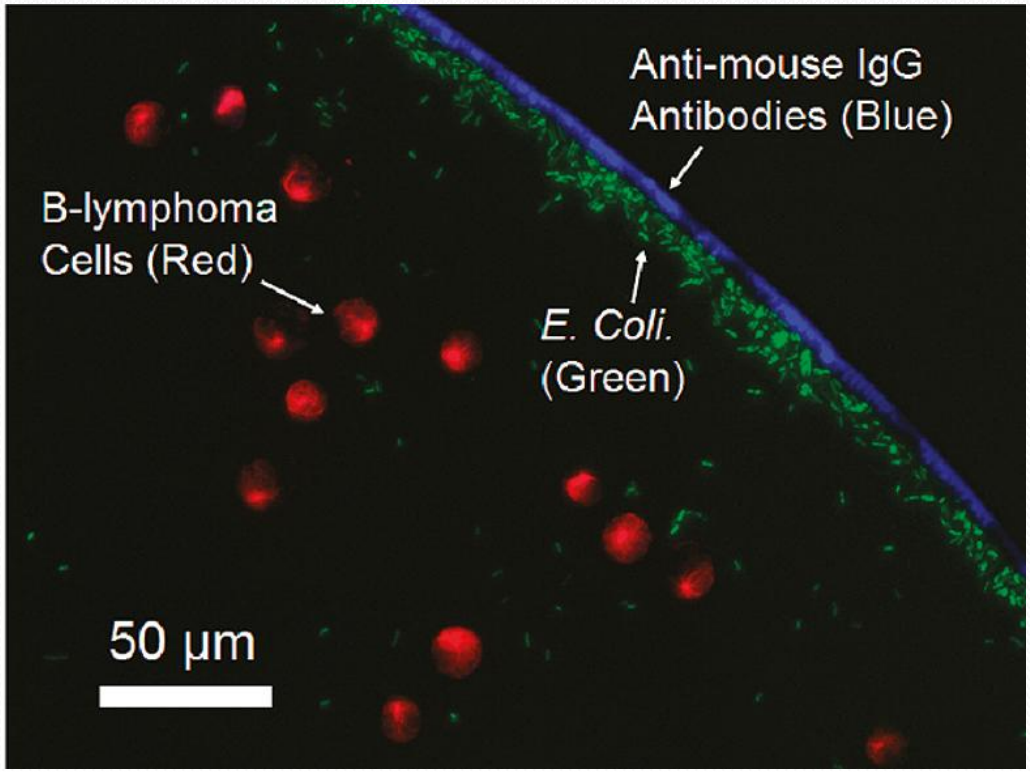


- Particle size
- Contact angle
- Reverse moving distance

Health Care Application

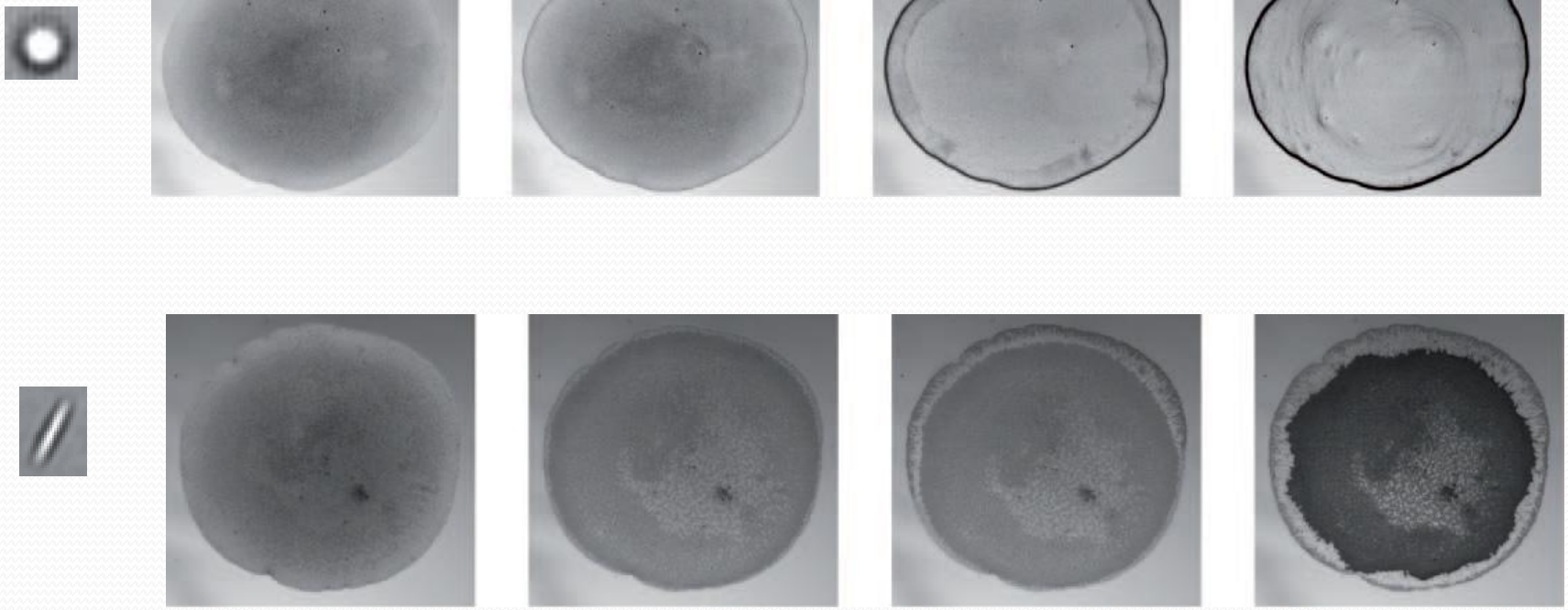
- Particle separation and concentration





Wong, T.S., et al., "Nanochromatography Driven by the Coffee Ring Effect", *Analytical Chemistry* **83**, (2011).

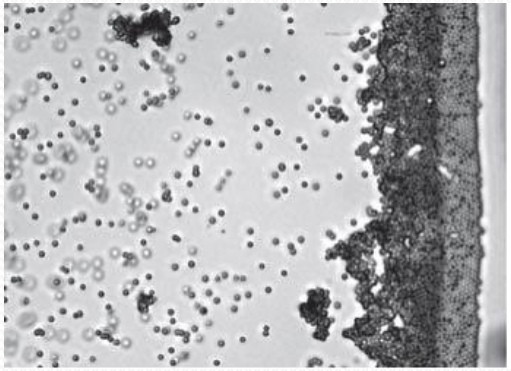
What about the shape of the particles?

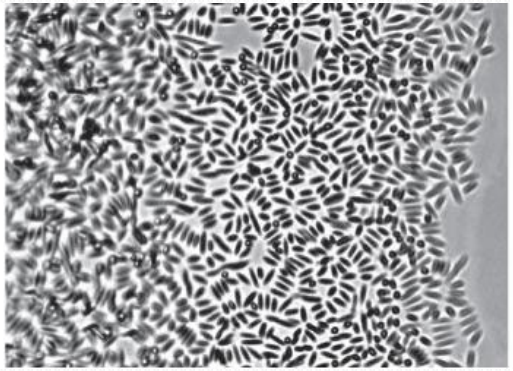


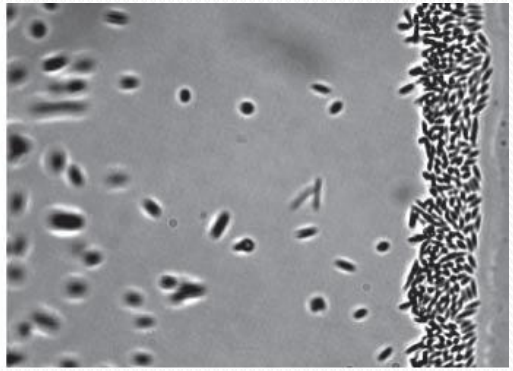
Yunker, P.J., et al, "Suppression of the coffee-ring effect by shape-dependent capillary interactions", *Nature* **476**,(2011).

…or is it the shape?

+ surfactant

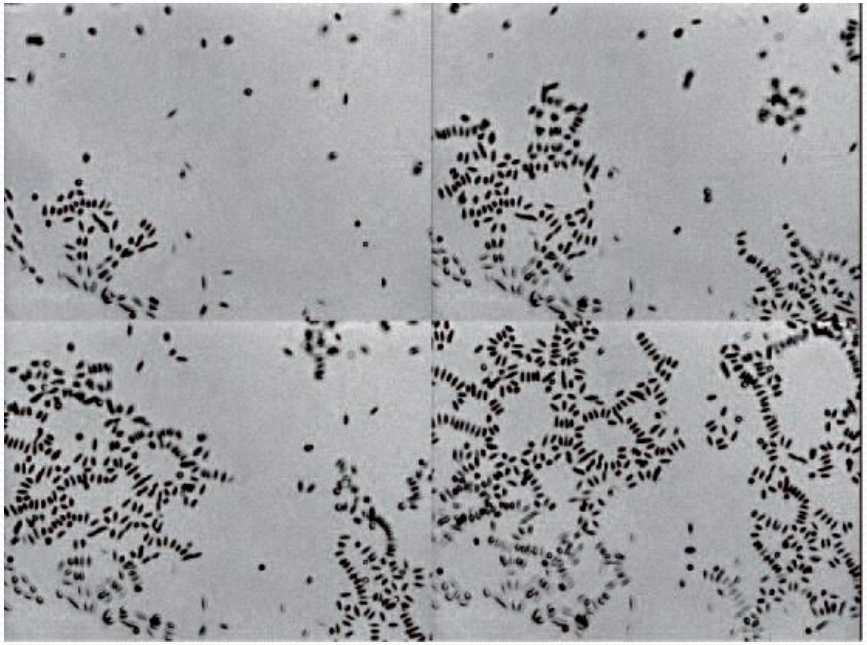




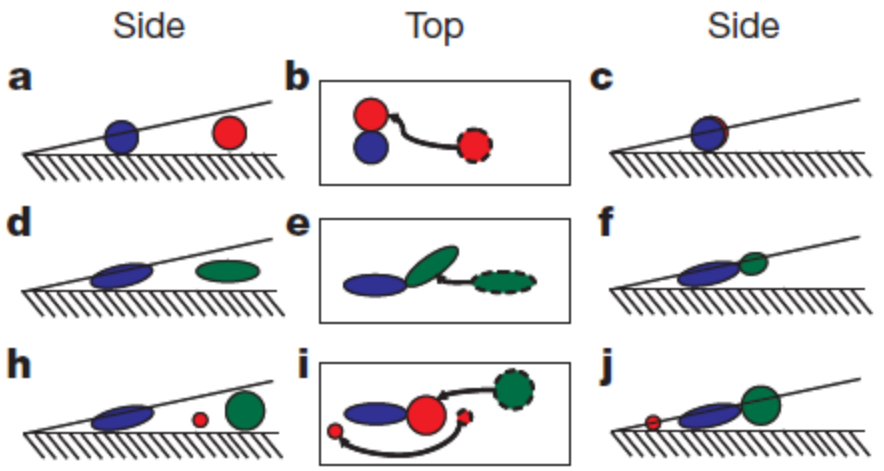


What's actually going on here?

- Strong ellipsoid-ellipsoid attractions
- Loosely packed structures deform the liquid surface
- Mobility is reduced



Non-Homogeneous Size/Shape Distribution



- Particle diameter > ellipsoid minor radius
- Volume fraction of ellipsoids ~ $2.5*10^{-5}$

Conclusion

- Temperature
- Surface tension
- Surfactants
- Particle size
- Particle shape
- Solvent
- Evaporation rate
- Viscosity?
- Particle material?
- Future research directions?